This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

Seismic Design and Retrofit of Systems and Components

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A Seven-Step Process

The seismic qualification process for systems and components entails the seven steps illustrated in Figure 1. These steps apply whether the task at hand is the design and qualification of a new system, or the seismic retrofit of an existing system.

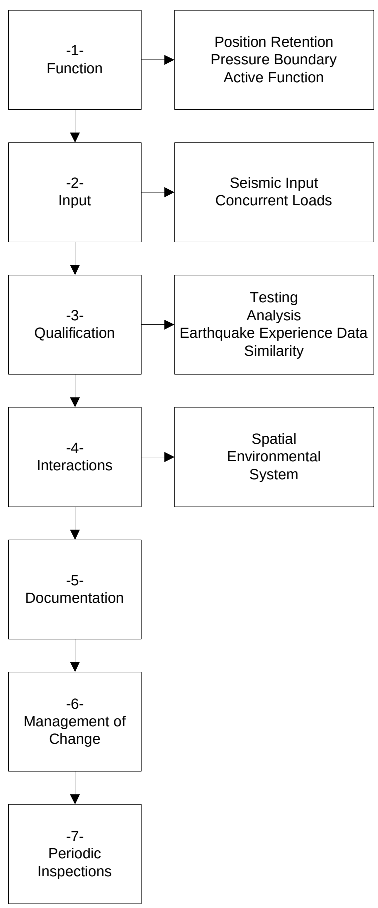

Figure 1 – The Seven Steps of Seismic Qualification

Classes of Systems and Components

The seven-step process applies to the following classes of systems and components:

Mechanical

Equipment and Components:

- Active (Dynamic, Rotating): such as pumps, compressors, fans, blowers, control valves.
- Passive (Static): such as tanks, vessels, heat exchangers, glove boxes.

Distribution Systems:

- Piping and tubing systems (including fittings, in-line components, manual valves).
- HVAC ducting systems.

Electrical, Instrumentation and Controls

Equipment and Components:

- Electrical equipment such as motor control centers, switchgear, transformers, batteries, panels, disconnect switches, automatic transfer switches, variable frequency drives, uninterruptible power supplies.
- Instrumentation and Controls such as transmitters, control panels, annunciators, pressure gages, monitors and alarms.

Distribution Systems:

- Conduit and cable trays.

Step 1 - Definition of Scope and Function

The functional requirements for systems and components are defined by the system-process and safety analysis engineers, through the safety analysis process, as one of the following three categories:

- Position Retention (PR)
- Pressure Boundary (PB)
- Active Function (AF)

Examples of earthquake damage include the pipe support that pulled out of the ceiling in Figure 2 causing the pipe to shift, this is a loss of "PR". The fire protection system illustrated in Figure 3 lost its pressure boundary integrity (PB) when it separated at pipe couplings. The pump shifted off its vibration isolator springs in Figure 4 causing a loss of active function.

Figure 2 - Failed Pipe Support (Loss of Position Retention)

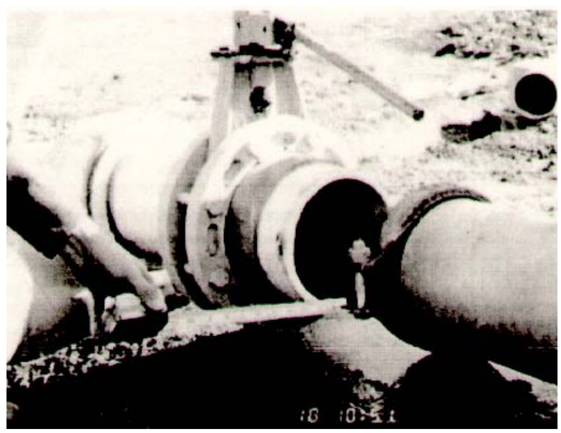

Figure 3 – Seismic Failure of Fire Protection Piping (Loss of Pressure Boundary)

Figure 4 – Failed Vibration Isolation Springs (Loss of Active Function)

The scope and function of systems and components should be stated succinctly in the following format:

- Indicate the seismic scope boundaries on process and instrumentation diagrams and electrical diagrams.
- Develop a seismic equipment list, which lists (a) the equipment, (b) its required seismic function, and (c) the calculations or reports that document its seismic qualification.

Where an active function (AF) is required, the scope shall include instrumentation and controls, and air, fluid and power supplies as required to perform the active function: an active pump must have its power supply and controls qualified.

Step 2 - Seismic Input and Concurrent Loads

In the Department of Energy approach to seismic qualification, the seismic input is a function of the Performance Category (PC) of the system or component, which is ranked PC1 to PC4 from least to most critical.

PC1 and PC2 input is typically based on ASCE 7 seismic forces, while certain PC2 and all PC3 input is building-specific.

The exceptions of ASCE 7 Section 9.6.1 apply to PC-1 Seismic Category D systems and components where all of the following criteria are met:

(a) Failure has no adverse interaction on PC2 or higher performance category systems and components.
(b) Flexible connections are provided between the equipment and associated ductwork, piping and conduit.
(c) Equipment weighs
    a. 20 lbs or less, or
    b. 400 lbs or less if mounted a no more than 4 ft above floor level, or
    c. distributed systems weigh 5 lb/ft or less

Loads concurrent with the Design Basis Earthquake are the loads corresponding to normal operating conditions, unless specified otherwise by the Design Authority. Normal operating loads are combined with seismic loads by absolute sum.

Seismic input must include inertia effects and differential seismic anchor motions. The results (loads, stresses, movements, strains) from these two effects are combined by SRSS.

For further conservatism, the seismic input for design by analysis of new PC3 and PC4 systems or equipment includes a margin of 20%, so that

$$\text{Design Spectrum} \geq 1.2 \times \text{IRS}$$

According to DOE Standard 1020, the seismic input (required response spectra RRS) for qualification by testing shall be a multiple of the in-structure response spectra (IRS),

for PC2 $\quad$ $\text{RRS} \geq 1.1 \times \text{IRS}$

and, for PC3 and PC4 $\quad$ $\text{RRS} \geq 1.7 \times \text{IRS}$

where 1.7 = 1.2 (the 20% design margin for new equipment) x 1.4 (test margin for PC3 and PC4).

Damping for seismic qualification shall is in accordance with ASCE 43 and DOE-EH-0545: Piping systems = 5%, Cable trays = 7%, Mechanical and electrical equipment = 5%, Vessels and non-flat bottom tanks = 5%, Flat bottom storage tanks = 4% impulsive and 0.5% sloshing, Electrical equipment, instruments and controls = 5%

Step 3 - Methods of Qualification

The seismic qualification of systems and components is achieved by one (or a combination) of four methods:

- Testing (AC156 for IBC-based seismic input, IEEE 344, IEEE 382, ASME QME 1): preferred method for active mechanical equipment, electrical equipment, instrumentation and controls.
- Analysis (ASME QME, IEEE 344-2004, applicable code for system or component): preferred method for passive mechanical equipment and distribution systems, and for electrical distribution systems.
- Earthquake experience data.
- Equipment may be qualified by similarity to previously qualified equipment. Qualification by similarity must address
  - Dynamic similarity of components.
  - Envelope of seismic input of previously qualified component.

This is the most standardized of all seven steps and applicable codes and standards for seismic qualification of systems and components are listed in Reference.

Seismic qualification must address end-of-life condition, in particular:

- Testing: determine the need for environmental qualification of electrical equipment (cables, batteries, etc.) and non-metallic components and trims.
- Analysis: deduct corrosion allowance when calculating stresses, address degradation mechanisms other than wall thinning (environmental cracking, fatigue, mechanical damage, etc.).
- Earthquake experience: assess the material condition and maintenance history of installed systems and components. For example, concrete cracking is a standard check for anchor bolts.

Figure 5 – Cracked Concrete Reduces Bolt Seismic Capacity

Step 4 - Assessment of Interactions

Seismic interactions may take one of three forms:

- Spatial Interactions: Damage or malfunction caused by impact between a failed or falling item or impact with an adjacent structure, equipment or component, Figure 6. Sources of spatial interactions may be evaluated using the criteria for position retention.

- Environmental Interactions: Environmental, spray, flood effects of fluid discharge from rupture or leak of unqualified systems or components, Figure 7. Sources of environmental interactions may be evaluated using the criteria for pressure boundary.
- System Interaction: Erroneous signals caused by unqualified systems or components. Sources of system interactions may be evaluated using the criteria for active function.

Credible and significant interactions between the source and the target (the equipment being qualified) must be documented in the calculation. Seismic sources of interactions shall be evaluated to the same Performance Category seismic input (demand) as the target.

Figure 6 – The Duct was a Source of Seismic Spatial Interaction

Figure 7 – The Loss of Tank Contents was an Environmental Interaction

Step 5 - Documentation

- Seismic qualification documents are to be filed in a retrievable manner and a summary report presenting the list and sequence of these documents is recommended.
- Vendor or contractor report should be reviewed, formally accepted and filed.

Step 6 - Configuration Management

The configuration of seismically qualified equipment and interaction sources must be maintained. Adequate configuration is required to prevent the introduction of credible and significant interactions during modifications or maintenance activities such the installation of scaffolding, the temporary removal of supports, attaching a come-along to a support or qualified equipment, not restraining wire slack, etc.

Step 7 - Periodic Inspections

Seismically qualified equipment should be periodically inspected to verify that its qualified condition is maintained, and has not deteriorated to the point where it can no longer perform its seismic function. The period between inspections shall be established on the basis of expected degradation mechanisms and prior operating experience.

References

DOE Standard 1020, Natural Phenomena Hazards Design and Evaluation Criteria for DOE Facilities.

DOE Standard 1021, Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems and Components.

ALA American Lifelines Alliance, Design of Buried Steel Pipe.

API 650, Welded Steel Tanks for Oil Storage, American Petroleum Institute, Washington, DC.

ASCE 4, Seismic Analysis of Safety-Related Nuclear Structures and Commentary, American Society of Civil Engineers, Reston, VA.

ASCE 43, Seismic Design Criteria for Structures, Systems and Components in Nuclear Facilities and Commentary, American Society of Civil Engineers, Reston, VA.

ASME AG-1 Code on Nuclear Air and Gas Treatment.

ASME B31.1 Power Piping, American Society of Mechanical Engineers, New York.

ASME B31.3 Process Piping, American Society of Mechanical Engineers, New York.

ASME Boiler and Pressure Vessel Code, American Society of Mechanical Engineers, New York.

ASME QME-1 Qualification of Active Mechanical Equipment, American Society of Mechanical Engineers, New York.

ASTM C 1172, Standard Specification for Laminated Architectural Flat Glass.

ASTM E 1300, Standard Practice for Determining Load Resistance of Glass in Buildings.

AWWA D-100, Standard for Welded Steel Tanks for Water Storage, American Water Works Association.

Brookhaven National Laboratory report BNL-52361, Bandyopadhyay, K., et. al., Seismic Design and Evaluation Guidelines for the Department of Energy High-Level Waste Storage Tanks and Appurtenances, Brookhaven National Laboratory, Upton, N.Y.

IBC, International Building Code.

ICBO AC 156, Acceptance Criteria for Seismic Qualification Testing of Nonstructural Components, AC156, International Conference of Building Officials, Whittier, CA.

IEEE-323, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations.

IEEE-344, IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Plant Generating Stations.

IEEE-382, IEEE Standard for Qualification of Safety Related Valve Actuators.

NFPA-13 Sprinkler Systems.

SMACNA 1299, Rectangular Industrial Duct Construction Standards.

SMACNA 1481, HVAC Duct Construction Standard, Metal and Flexible.

SMACNA 1520, Round Industrial Duct Construction Standards.

SMACNA 1650, Seismic Restraint Manual Guidelines for Mechanical Systems.